

REMARKS

This paper responds to the Office Action dated December 3, 2001.

Claims 1-36 were pending at the time of the Office Action. Claims 1-36 have been canceled and new claims 37-71 have been added. The new claims correspond roughly with the old claims as follows:

old	1, 9	2	3	4	5	6	7	8	10
new	37	38	39	40	41	42	43	44	45

old	11	12	13	14	15	16	17	18	19
new	46	47	48	49	50	51	52	53	54

old 20 21 22, 9 23 24 25 26 27 28
new 55 56 57 58 59 60 61 62 63

old	29	30	31	32	33	34	35	1, 9, 36
new	64	65	66	67	68	69	70	71

Claim Rejections 35 USC §112

Claims 16 and 27. The Examiner rejected claims 16 and 27 as supposedly indefinite. The Examiner stated that he was unclear as to the structure used for cavity dumping.

It is respectfully suggested that "cavity dumping" is a method of coupling out radiation from a laser cavity. An acousto-optic device is suddenly switched on, by which a beam path out of the cavity is provided, so that energy is nearly instantly dumped from the laser cavity. It is further respectfully suggested that "cavity dumping" has a definite and well-known meaning in the art.

5 Attached please find a copy of an extract from a standard solid-state laser textbook, namely W. Koechner, Solid-State Laser Engineering, 5th ed., (Springer-Verlag, Berlin, 1999). In the extract, cavity dumping is explained,

Reconsideration of the rejection of claims 16 and 27 is thus respectfully requested.

10 **Claim 36.** The Examiner rejected claim 36 as supposedly indefinite, being a method claim depending from an apparatus claim (claim 1). New claim 71 has been introduced which is intended to correspond with former claim 36, incorporating limitations from former claims 1 and 9. Claim 71 does not depend from any other claim.

Claim Rejections 35 USC §103

15 The former independent claims were claims 1, 22, and 36. New independent claims 37, 57, and 71 are now present. Each of these claims incorporates the subject matter of former claim 9.

In the office action, the Examiner stated that the subject matter of the former claims 1 and 22 as well as of some dependent claims was made obvious over Kasamatsu et al. (Applied Optics, Laser-Diode-pumped Nd:YAG active mirror laser, "Kasamatsu") and Weingarten et al. US Pat. No. 5,987,049 ("Weingarten"). It is respectfully suggested that the subject matter of the new independent claims is not made obvious by the cited references.

Kasamatsu shows a thin-disk laser, the thin-disk laser medium being mounted on a cooling surface. However, Kasamatsu shows a *continuous-wave (cw) laser* (see page 1879, second column), and *not a laser for emitting pulsed electromagnetic radiation* as in the claimed

preamble

invention.

The requirements for continuous-wave lasers differ in many aspects from the requirements for of pulsed lasers. Whereas the cavity of cw lasers is designed to provide a monochromatic, coherent output beam, in pulse-generating lasers the cavity has to be designed to optimize the pulse

5 duration (i.e. to provide short pulses) and/or the repetition rate. For example, in mode-locked lasers, the cavity lengths directly defines the pulse repetition rate. This means that in order to obtain the desired high pulse intensity, the cavity has to be of a much greater size for pulse generating lasers than for the laser of Kasamatsu. More generally, there are fewer degrees of freedom available to the designers of pulse-generating lasers.

10 For these reasons, cw lasers and pulse-generating lasers are completely different fields, in which different search groups are active, which concern different laser manufacturing industries etc. For example, the assignee of this application is a manufacturer of pulse generating lasers and would not have the know-how for fabricating a competitive cw laser. The expert in the field of pulse-generating lasers would thus never consider the Kasamatsu reference. However, even if we were 15 to assume for sake of discussion that he would, the following comments would apply.

The examiner correctly points out that Weingarten discloses a semiconductor saturable absorber mirror (SESAM) for passive mode locking of a resonator. However, the laser shown by Weingarten is merely a low average output power pulse generating laser.

20 In fact, SESAMs as such have been known in the art for several years now. However, the expert has *no motivation whatsoever* to introduce such a SESAM into the laser device of Kasamatsu. SESAMs are exclusively useful for mode-locking in pulsed lasers. Introduced in a cw laser such as Kasamatsu's, they would inevitably render the laser unusable. None of the cavity design parameters would be suited for a pulse generating laser (see the description by Kasamatsu on pages 1879-1880). Additionally, SESAMs bring about losses (saturable and non-saturable 25 losses). They also are delicate parts which tend to be thermally damaged quite easily.

Compared to the teaching of Kasamatsu, a cavity for a *pulse generating laser* would have to be redesigned from scratch in order to function properly.

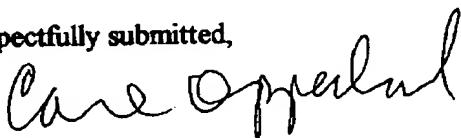
More generally, the expert will *not consider* introducing a saturable absorber in a high average output power laser such as a cooled-thin-disk-laser. The reasons for this are set out on page 4 of 5 the specification of the present application. They are also described in the German patent application publication DE19907722, mentioned at page 4 of the specification. Lines 17-30 of Column 2 of this publication translate as follows:

10 For laser systems with high power (some 100mW) and on another basis (cf. e.g. EP0492944A2) a method for passively mode locking by means of a Kerr lens device was provided, wherein no hints towards an application in high power laser systems with ultra-short pulses can be found, though. Rather, further progress has been achieved using 15 semiconductor based saturable absorbers (SESAMs), which, however, have proven to be too short-lived for high power laser systems, regarding their applicability for powers above some 100mW. On the other hand, non-linear optical methods are preferred, since they are power scaleable by means of appropriate focussing of the beam, and since they do not rely on direct absorption of radiation.

20 It is an *achievement* of this invention as defined in the independent claims to have *considered and reduced to practice* introducing saturable absorbers into a laser with a laser gain medium having two end faces, and at least one of said end faces comprising a cooling surface, i.e. a laser being designed for high power operation.

For all these reasons, reconsideration is requested.

Respectfully submitted,



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4.6 Cavity Dumping 315

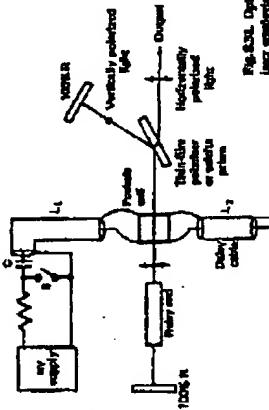


Fig. 4.6. Optical layout of a ruby laser employing cavity dumping

the bias on the Pockels cell is reduced to zero after this time delay. This can be accomplished by means of the circuit shown in Fig. 4.31. In this arrangement, the Pockels cell is connected in line between conductors 1₁ and 1₂. Charging the switch S will discharge the capacitor C into the transmission lines 1₁ and 1₂. During the voltage pulse reaches the Pockels cell, the optical beam will experience a 90° polarization rotation and the Q-switched pulse will start to build up from noise. Assuming a typical 3042 temperature of the Pockels cell, no reflection will occur at the cell and the voltage pulse will travel to the end of the shorted transmission line 1₂. At this point the pulse will be reflected with a 180° phase shift. When this reflection reaches the cell, the voltage on the crystal will be zero. Therefore the length of cable 1₂ determines for how long the voltage is applied to the Pockels cell.

The performance of a ruby oscillator having the above-mentioned system parameters is illustrated in Fig. 4.32. Shown is the power inside the resonator if the energy is not dumped (Figs. 4.32a). The measurement was made by monitoring the leakage radiation through one of the 99% mirrors with a fast detector and oscilloscope. The peak power and energy inside the resonator were determined to be 190 Mw and 1.1, respectively. Figure 4.32b depicts the circulating power submitted through the same mirror if the energy is dumped and the system is operated as a YTM oscillator. The leaked energy power reaches almost the same value as in Fig. 4.32a, then fall in about 5 ns to almost zero. This means that all but a small percentage of the available energy has been dumped from the cavity. Figure 4.32c records also the dumped pulse in integrator, with a 10 to 90% rise time of 3.0 ns and a pulse width of 3.3 ns. This which corresponds exactly with the cavity round-trip transit time within experimental error. The total energy of this pulse was measured to be 0.75 J. The peak power of this pulse is then 1.4×10^8 W. The rise time of the energy pulse is determined by the switching speed of the hydrogen thyatron which was used to discharge capacitor C. The experimental data indicates that 25% of the stored energy was extracted from the resonator.

3.4 3. Q-Switches

to be concerned by means of a parametric oscillator or Raman cell (Chap. 10). An alternative approach for cavity dumping is based on flashlamp or diode pumped Q-switch lasers which directly emit at the desired wavelength. The most popular method of Q-switching such lasers is the rotating Photo plate. However, recently, passive Q-switches based on intrinsic doped CdTe have been developed for this laser [8.87, 88].

3.6 Cavity Dumping

A means for generating extremely short Q-switched laser pulses involves Q-switching the laser with 100% reflectors on both ends of the cavity and then, at the peak of the circulating power, rapidly switching the output mirror from 100 to 0% reflection. This leads to a rapid dumping of the entire optical energy from within the cavity. One of the advantages of this technique is the production of Q-switched pulses whose width is mainly a function of the oscillator cavity length, rather than the gain characteristics of the laser medium. Specifically, the laser pulse width at the half-power points will be equivalent to the round-trip transit time to the cavity, with the condition that the Q-switched amplitude be switched within this same time period. Thus, based on allowable cavity dimensions, pulse widths in the range of 2 to 5 ns are feasible for oscillators whose pulse widths are of the order of 10 to 20 ns in the normal Q-switch mode.

Figure 3.31 shows the optical layout of a ruby oscillator designed to generate short pulses by the cavity dumping mode. We will explain the operation of this system by assuming that the ruby c plane is perpendicular to the plane of the paper. When the flashlamp is fired the horizontally polarized ruby fluorescence is transmitted by the thin-film or cat's-eye polarizer, thereby providing regeneration. Upon reaching peak-energy storage in the ruby, the Pockels cell is biased to its half-wave retardation voltage. The resulting vertically polarized light is reflected by the polarizer to the off-axis mirror, and regeneration occurs in the cavity. When the power in the cavity reaches its peak value, the bias is removed from the Pockels cell in a time period of about 2 ns. The cavity energy then linearly drains out of the cavity in the time required for the reflection to travel one round trip in the optical cavity. The combination of the polarizer, Pockels cell, and 100% mirror combination which amounts to a 180°-spaced voltage-retardation mirror whose reflectivity is changed from 0 during the pumping cycle to 100% during the pulse buildup, and back to 0 during the cavity dumping pulse.

To illustrate the practical usefulness of this technique, we will consider a typical ruby oscillator consisting of a 10-cm by 1-cm ruby rod, a Pockels cell, a thin-film polarizer, and two 99% mirrors. If we assume a 75-cm-long cavity, we obtain a round-trip transit time of 5 ns. The ruby rod is pumped by a 1-mA-long flashlamp probe, and the Pockels cell is switched the first time after about 0.5 ns. The time delay between switching the Pockels cell and the commencement of peak power in the cavity is typically 60 ns. In order to extract the stored cavity energy,

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6.6. Cavity Damping 57

The basic building block of the field inside the laser cavity and the class of damping of the invention are an upper limit to the repetition rate established from the available lasers. This maximum value of repetition rate for Q-switched lasers is of the order of 50 to 100 kHz. Cavity damping of continuously pumped lasers is a way to obtain pulsed output at higher repetition rates than are available by Q-switching. Repetition rates from 125 kHz up to several megahertz for cavity damping were achieved with cw-pumped Nd:YAG lasers [156, 157].

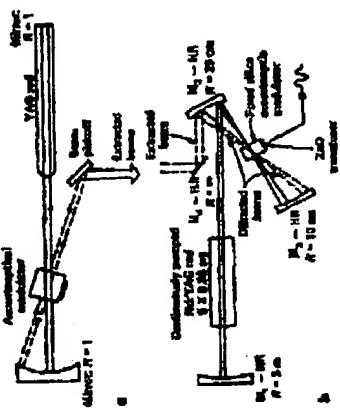


Fig. 6.6.1: Schematic diagram of a cavity damping system [156, 157].

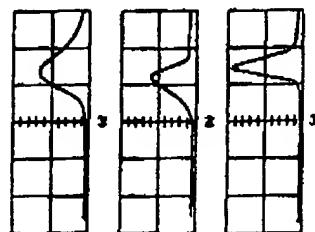
In practical situations the design of cavity damped lasers is completely dictated by the requirement of keeping the power density within the cavity below the damage level. The usual cavity polarizer, being the component with the lowest damage threshold, has been replaced by a compensatory oscillator by highly compensated thin-film polarizers. These components permit oscillations to operate at power densities up to 300 J/cm² [158].

It is not necessary in a cavity damped system to use the same Pockels cell for both the Q-switch initiation and cavity damping. Both systems employ transmission line a wave guide, synchronization between the peak power in the cavity and the switching of the Pockels cell can be achieved if the cavity radiation is monitored by a detector mounted behind one of the 50% mirrors [159]. Other variations of cavity damping are described in [150-153]. The technique can be employed in any solid-state laser, for example, Nd:YAG oscillators have produced 100 pulses with energies up to 100 mJ [157]. Similar examples of cavity damped systems are given in Secs. 5.3.2 and 9.4.3 in connection with double-pumped indirectly mode locked oscillators or with regenerative amplifiers. Cavity damping is also possible with cw-pumped lasers; this will be discussed next.

Cavity Damping of CW-Pumped Lasers

Cavity damping can be compared with the Q-switching of a continuously pumped laser. In both cases energy is transferred to the damped beam in the form of an impulsive train of light pulses. However, cavity accumulations and storage between voltage pulses are extremely in the optical field for cavity damping, particularly in the population inversion in the Q-switching.

6.7. Oscillations



In practical situations the design of cavity damped lasers is completely dictated by the requirement of keeping the power density within the cavity below the damage level. The usual cavity polarizer, being the component with the lowest damage threshold, has been replaced by a compensatory oscillator by highly compensated thin-film polarizers. These components permit oscillations to operate at power densities up to 300 J/cm² [158].

It is not necessary in a cavity damped system to use the same Pockels cell for both the Q-switch initiation and cavity damping. Both systems employ transmission line a wave guide, synchronization between the peak power in the cavity and the switching of the Pockels cell can be achieved if the cavity radiation is monitored by a detector mounted behind one of the 50% mirrors [159]. Other variations of cavity damping are described in [150-153]. The technique can be employed in any solid-state laser, for example, Nd:YAG oscillators have produced 100 pulses with energies up to 100 mJ [157]. Similar examples of cavity damped systems are given in Secs. 5.3.2 and 9.4.3 in connection with double-pumped indirectly mode locked oscillators or with regenerative amplifiers. Cavity damping is also possible with cw-pumped lasers; this will be discussed next.

Figure 6.7.1 exhibits two common arrangements employed for cavity damping of cw-pumped solid-state lasers [156, 157]. Essentially all types of this type employ accumulative accumulators as the protecting element. In order to obtain fast switching action, the incident beam must be focused to a narrow spot under hostile conditions. The two oscillator designs differ in the way the optical beam is focused into the oscillator.

In Fig. 6.7.1a the oscillator is located at a beam waist created by a converging lens and by the divergent lens properties of the laser rod. The oscillator beam is then focused after passing through of the converging- and backward-coupling lens beam in the oscillator. The two different beams which are obtained from the cavity-damped oscillator are initially traveling in opposite directions, therefore their characteristic are shifted to a value of $\alpha + \beta$ and $\alpha - \beta$, where α is the cavity characteristic and β is the frequency of the incident beam and β is the frequency of the oscillator beam [156, 157]. The two different beams are collected from the cavity in a single lens and delivered out of the system by a mirror. In Fig. 6.7.1b the cavity is

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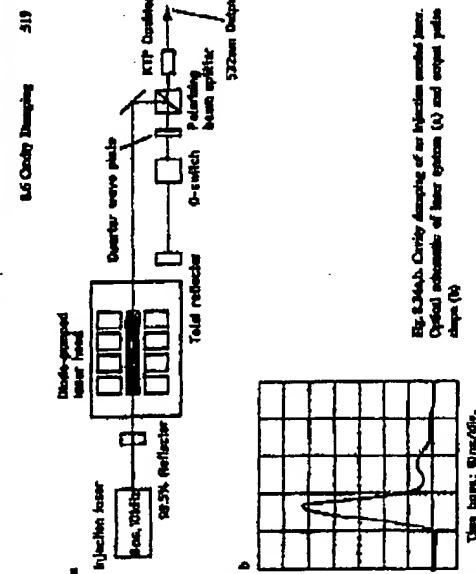


Fig. 8.34b. Cavity dumping of an Nd:YAG laser system (1) and output pulse shape (2).

formed by three high-reflectivity mirrors M_1 , M_2 , and M_3 . The mirror curvatures and the distance between M_2 and M_3 are chosen such that the light beam between M_1 and M_2 is focused to a small diameter at the center of curvature of M_3 . The modulator is inserted at the waist of the optical beam.

Acousto-optic modulators employed for cavity dumping differ from those commonly used in Q-switch applications in several respects:

- 1) Compared to Q-switching, the cavity-dump mode requires much faster switching speeds. The rise time in an acousto-optic modulator is approximately given by the beam diameter divided by the velocity of the acoustic wave. In order to obtain rise times around 5 ns, a value which is required for efficient cavity dumping, the incident beam must be focused to a diameter of approximately 50 μ m.

- 2) For efficient operation in the cavity-dump mode, it is important that essentially all the circulating power be diffraction-limited into the first diffraction order. In a Bragg device the diffraction efficiency increases with the off-cavity frequency, therefore modulators employed in cavity dumpers operate at considerably higher frequencies, i.e., 200 to 500 MHz as compared to acoustooptic Q-switches.

3) In order to generate an output pulse in the cavity-dump mode, a short rf pulse is applied to the modulator; whereas in an acoustooptic Q-switch the rf carrier is turned off for the generation of an output pulse.

- 4) The cavity is never kept below threshold conditions as in the Q-switched mode of operation. If the cavity is pumped at all its energy, the field has to build itself from the noise level. Repetitive cavity dumping was observed to become unstable in this case. If the repetition rate is lowered, the laser material is pumped higher above threshold between pulses, therefore, a larger fraction of the stored energy is extracted from the system (see Sect. 8.1). The lower limit of the dumping repetition rate is reached when the internal laser energy decreases to one photon immediately after dumping. The upper limit of the cavity dumping repetition rate is set by the switching speed of the modulator. Repetition rates as high as 10 MHz have been reported. From a cw-pumped Nd:YAG laser capable of 10 W of cw power, peak powers of 270 W with a pulse duration of 25 ns have been obtained at a 2 MHz repetition rate [18,104]. For high-data-rate communications systems, cavity dumping of cw-pumped lasers is sometimes combined with mode locking [8.10,102].

The technique of cavity dumping is also employed in regenerative systems. In a regenerative laser a pulse is injected into a laser resonator containing an amplifier. The pulse passes several times through the same amplifier medium and is then switched out. Figure 8.34c shows an optical schematic of a laser which employs this technique [8.105]. Illustrated is a diode-pumped Nd:YAG crystal located between two highly reflective mirrors, a Pockels cell Q-switch and a polarizer. The Nd:YAG crystal is compensated and repetitively cavity dumped at a 10 MHz repetition rate. During the 100 μ s pump time, the Pockels cell is